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Research Article

Investigation and Future Directions of the Intelligent Workshop AGV Path Planning Algorithm

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Abstract:
One of the main algorithms used by automatic guided vehicles (AGVs) to carry out the autonomous work of an intelligent workshop is the path planning algorithm. The study status of the Viewable technique and Grid method in domestic and international environment modelling is presented. Analysed and contrasted with intelligent algorithms like particle swarm optimisation, ant colony algorithm, and genetic algorithm are the research findings of conventional path search algorithms like artificial potential field technique, Dijstra algorithm, and A* algorithm. As a result, research will concentrate on fusing intelligent and conventional algorithms to increase the operational effectiveness and effective obstacle avoidance of AGVs, beginning with algorithm enhancement. In conclusion, the present study trend in AGV route planning research is confronted with the issues of intelligent development and integrated development. Future studies could take into account enhancing algorithm performance and integrating it with cutting-edge innovations like artificial intelligence.

Keywords; algorithm improvement; Path planning; automatic guided vehicle （AGV).

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INTRODUCTION

At present, with the continuous progress of human science and technology, factories in the traditional sense consume too much manpower and material resources, and the corresponding work cost of enterprises has also increased. This traditional work mode is no longer applicable in the face of a large number of complex work tasks. With the introduction of intelligent machines in medical, catering, logistics and other fields, their work efficiency is greatly improved compared with human labor, such as medical robots, catering robots, transportation robots and so on. In order to ensure the safety of staff, many high-risk operations are also replaced by intelligent machines. As a result, AGV is already a crucial component of many smart factories, and it is currently being more closely integrated with big data and the Internet to enhance the logistics system's perception and autonomous decision-making capabilities. Research on AGVs started when the first one was created in 1953. It was

a modified version of a basic AGC product tractor, and its cargo had to be flown over an air wire (Jian., 2024). The United Kingdom was the first to develop electromagnetic induction guided AGV, soon Europe installed a variety of forms, different levels of AGV, early AGV as shown in Fig1, by the mid-1970s, due to the popularity of microprocessor and computer technology, servo drive technology mature design more flexible AGV.

The paths of AGV operations are long and short, and the paths of multi-AGV operations are complicated, and the path problem is related to work efficiency and operation cost. Consequently, path planning is both essential to the execution of AGV activities and the primary technical application issue, garnering significant interest from domestic and international experts (Aggarwal & Kumar., 2020). Path search and environment modelling are the two categories into which AGV path planning methods are separated in this work. A sensible approach to environment modelling can assist cut down on the number of path searches; various path search algorithms rely on different representations of the environment. Typical techniques for modelling an environment include the grid approach, the viewable method, and others. Artificial potential field method, genetic algorithm, particle swarm optimisation algorithm, ant colony algorithm, and other algorithms are examples of path search algorithms. The algorithm design is the fundamental component of AGV path planning technology. The optimization of AGV job paths by different algorithms can be adapted to a wider range of scenarios. Zhu Mingzhe and Sun Bingyu (Mingzhe & Bingyu., 2021) studied the global search ability of genetic algorithm and the conflict prediction ability of time window algorithm. They solved the congestion problem, but did not pay attention to the operation path. This paper reviews how to optimize AGV path, speed up algorithm convergence and improve AGV efficiency by improving intelligent algorithm or combining intelligent algorithm with traditional algorithm in recent years.

Fig 1. Agvs for early factory applications

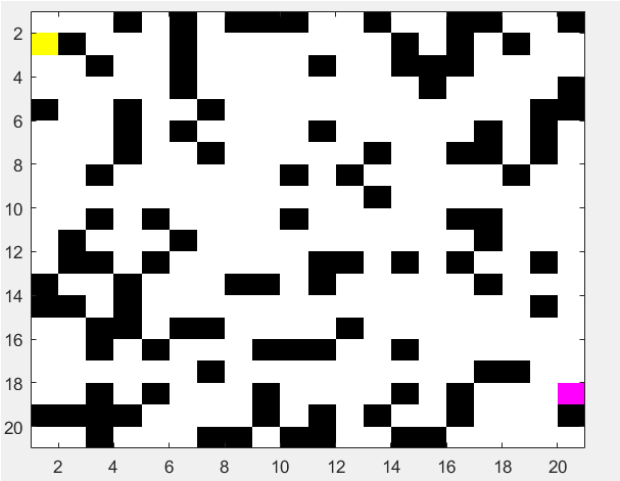
Path Planning Algorithm Based On Environment Modeling

For the processing of environmental information, through the construction of effective mathematical models, environmental information can be better understood, effective analysis and optimization of the environment can be realized, environmental problems can be modelled and solved by mathematical optimization methods, and paths can be searched and optimized. When solving the problem, the corresponding modelling method is helpful to reduce the calculation amount of path planning and speed up the calculation.

GRID METHOD

The Grid-based Method, initially introduced by W.E. Bowden in 1968, is a widely utilised mathematical modelling tool that is mostly employed for path planning and environmental modelling. Particularly well-suited for handling geographic and spatial data by dividing the space area into regular grids or cells and storing the corresponding information in each grid or cell, the grid method in environmental information processing simulates obstacles into a collection of small squares, which is equivalent to the binary substitution of all objects in the scene, with obstacles represented as 1 and non-obstacles as 0. Fig. 2 depicts the intelligent workshop environment modelling. This technique is applicable to the creation of maps, environmental simulation, geographic information systems (GIS), and other domains. Each grid or cell in the raster approach typically represents a particular area of space with predetermined dimensions and characteristics. Discrete representation and processing of spatial information can be realised by storing environmental data in each grid or cell. The environmental information displayed by the grid map will be very visible if the grid is tiny. However, as more information needs to be kept, the cost of storage will go up, slowing down planning and limiting real-time performance. On the other hand, the limited amount of information storage speeds up planning, but it also causes fuzziness in the way environmental information is divided, making path planning less effective. In order to replicate the real working environment, Jiang L (Longteng et al., 2024) constructed raster maps, randomly assigned obstacle information, and created a full-coverage path planning method based on the neuron excitation network method. This method is capable of realising large-scale coverage of farmland plots and achieving independent optimal path planning for obstacle maps of varying complexity. Qiu T (Tian et al., 2022) in addition to others Using alternative sampling procedures, the sample locations were connected; they were no longer crossed, but only connected with neighbouring grids. The map was divided by grid, and the threat level of each grid was divided based on the obstacle area within the grid. The outcomes demonstrated a decrease in operating time and an improvement in success rate. The raster technique, a popular AGV path planning methodology, typically needs to be supplemented with other path search methods for path planning because it is challenging to solve the complicated environment information problem directly.

Fig 2. Smart workshop environment map



Viewable Method

The viewable method is a classical technique for robot global motion planning that was first presented by Lozano-Perez and Wesley in 1979. Robots are represented as points in the Viewable technique, and obstacles by polygons. Starting point S, target point G, and the polygon obstacle's vertices are joined and connected. This means that the lines connecting the starting point and obstacle, the target point and obstacle, and the obstacle's vertices must not cross each other; in other words, the straight line must be "visible" through the obstacle. In Figure 3, the Viewable technique is displayed. The complexity of the algorithm increases with the number of obstacles. The Viewable method is typically appropriate for polygonal obstacles; however, if the starting point and the target point are altered, the method must be recreated. The failure of circular obstacles can be enhanced through the use of the Voronoi diagram and tangential graph methods. Through the combined use of UHF and low frequency radio frequency identification systems, as well as the Viewable method and A* algorithm to increase search efficiency and guarantee the viability of the planned path, (Chao et al., 2014) achieved accurate positioning. In order to optimise the initial path, construct the optimised path for the inadequacies, and then carry out the secondary optimisation, Liu Y (Ya., 2012) integrated the Viewable technique with the convex point approach. In order to build a sub-optimized path that leads to a better path, each node in the path generated for the initial optimisation is successively chosen as the new starting point and end point.

AGV path planning algorithm research will increasingly focus on 3D environment modelling due to the increasing computational speed of AGVs and the requirement to maintain the integrity of shop environment data. The benefits and drawbacks of the aforementioned popular environmental modelling techniques are displayed in Table 1.

Fig 3. Viewable method

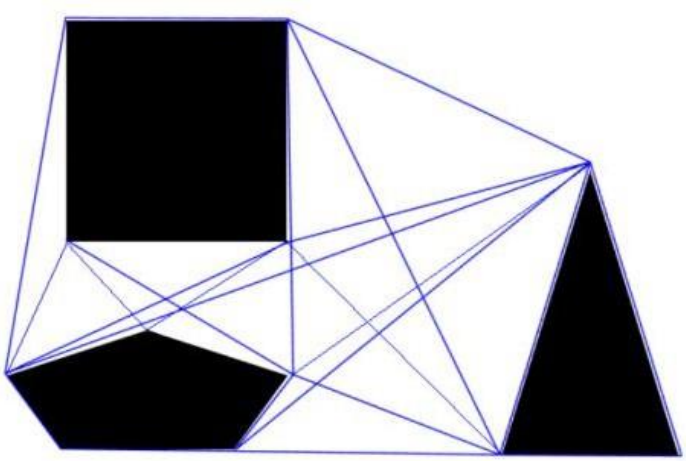


Table 1. Comparison of common environment modeling methods

method	advantage	shortcoming	reference	Scope of application
Grid method	Simple and effective, with scalability, visualization and interpretability, simple modeling process	The space and calculation cost are large, the accuracy is limited, the data update is difficult, and it is not suitable for large-scale spatial search	(Aggarwal & Kumar., 2020; Mingzhe & Bingyu., 2021)	Autonomous driving, robot positioning and path planning, building the geographic layout of the game world
Viewable method	Intuitive concept, Simple implementation, easy to find the shortest path	Long search time, lack of flexibility, local path planning ability is poor	(Longteng et al., 2024; Tian et al., 2022)	Geographical scenario prediction of outdoor environment, Marine environment modeling

Path Planning Algorithm Based on Path Search

To find the shortest route between the start and finish of the search path, the path search algorithm relies on the pre-existing environment model. Numerous path search algorithms exist; each has unique characteristics, and each application sector is distinct. Conventional optimisation techniques are often designed for structured problems, meaning that the requirements and issue descriptions are more explicit. Convex optimisation is a subset of many conventional optimisation techniques that has the distinct and unmistakable global best advantage. There are two components to path planning: local and global. The majority of study focuses on finding the global optimal solution or avoiding local minimums. As opposed to a global minimum, a local minimum is a minimum within a certain area. The best outcome found through worldwide research is known as the global optimum. The more advanced task needs are no longer met by conventional path search techniques due to scientific and technological advancements. The theory is not without flaws, though; for example, it has limited search capacity, and intelligent optimisation algorithms tend to focus on multi-extremum problems. In order to maximise the likelihood of finding the global optimal solution while avoiding local optimality, intelligent algorithms are frequently integrated with

classical algorithms. Alternatively, based on the initial algorithm to enhance its adaptation to the particular work scenario.

Traditional Path Search Algorithm

While the classic path search technique is straightforward and simple to use, it has certain drawbacks, including low processing speed, inadequate dynamic obstacle avoidance capability, and poor path optimisation effect (poor feasibility). The artificial potential field method, Dijkstra algorithm, A* algorithm, and other conventional path search methods are frequently employed in AGVs.

Artificial potential field method

Khatib proposed the artificial potential field approach as a virtual force method for robot motion planning. The main concept is to make tangible how barriers and objects affect the robot's movements. The potential energy is high at the impediment and low at the target. The robot is controlled to move towards the target point along the negative gradient of the potential field by the combination of the attraction of the target and the repulsion of the obstacle, which are produced by this type of potential difference. Although the path that is produced by the artificial potential field approach is safe and smooth and can be easily calculated, the complicated potential field environment may result in local minima outside the target point, which would prevent the robot from reaching the goal. Scholars have offered a number of improved solutions to tackle the artificial potential field method's local minimum point problem. It can be broken down into two directions creating an appropriate potential function to lessen or prevent local minima: The other involves using different techniques to force the robot to exit the local minimum once it has come into contact with it. In order to sample the potential field, Saravanakumar (Saravanakumar & Asokan., 2013). devised a directed search method based on the conventional APF algorithm. The vehicle can be moved to the spot in three dimensions to analyse the local minimum problem by locating the point of minimal potential energy. The local minimum burden is avoided by decreasing the proportional factor of the fine-tuning potential function. Thus, in three-dimensional space, local minima can be avoided. In order to further enhance the artificial potential field method and combine it with the variable dimension particle swarm optimisation algorithm to find an optimal path by dynamically adjusting the number and distribution of path nodes, (Yan et al., 2014) proposed a dynamic formation model in a complex underwater environment. An enhanced artificial potential field approach based on fuzzy control and virtual target points was presented by (Guosheng et al., 2024) to address the issues with local minimum trap and path redundancy that arise in robot local path planning. The enhanced APF algorithm can eliminate the trap fast, cut down on unnecessary paths, enhance path smoothness, and save planning time.

Dijkstra algorithm

E.W. Djkstra proposed the Dijkstra algorithm in 1959. The technique uses a greedy mode that allows it to solve the shortest path issue in the power graph and determine the shortest path from one vertex to all other vertices. The primary characteristic is beginning at the beginning, utilising the greedy algorithm approach, and repeatedly traversing the neighbouring nodes of the nearest and unexplored vertices to the starting point till it is reached by the end. For graphs where the weights are non-negative, the algorithm performs best. In order to discover the shortest anti-conflict path for multi-UAVs, Huang Y and Yu (Yihu & Yanan., 2022) suggested an enhanced Dijkstra algorithm due to the drawbacks of previous techniques, such as less than optimum temporal complexity. By using a time frame conflict judgement model and a variable length backtracking array, the shortest path was established. From there, plausible non-conflicting routes could be identified. An updated Dijkstra algorithm-based

optimised scheduling strategy was presented by Sun (Ning et al., 2022) to address the issue of lengthy wait times and inefficient traffic when cars cross an intersection without signal lights. By utilising the adjacency list and binary sort tree structure, (Xianquan., 2021) enhanced the conventional Dijkstra algorithm, allowing the emergency command truck to efficiently and quickly handle a variety of situations on congested metropolitan roadways.

A* algorithm

The A* algorithm is a fast search method for determining the shortest path in static networks. It was first presented in 1968 by Peter Hart, Nils Nilsson, and Bertram Raphael at the Stanford Research Institute. The precision of the heuristic function employed is crucial to the A* algorithm's performance. If the heuristic is admissible and consistent, then A* is optimal and complete. Zhang W, Zhang Z, and Wang W (Wei et al., 2024) presented an enhanced A* method with adaptive search distance to more effectively address the issues of huge extended search range and easy path collision in global path planning. In order to decrease the number of extended search nodes and shorten search times, the adaptive adjustment of search distance mechanism in eight directions replaces the initial fixed search distance throughout the path extended search process. Shi X and others (Xun et al., 2024) proposed A robot navigation method based on the improved A* algorithm, which uses the nth-order Bessel curve to smooth the path twists caused by the small-range A* algorithm, and only uses the small-range A* programming. The cost of the heuristic path obtained by using A* algorithm is low, and its advantage is that it can be interrupted and restored in time during the planning process.

The research on the above commonly used traditional search methods is shown in Table 2.

Table 2. Comparison of traditional search methods

Traditional algorithm	advantage	shortcoming	reference	Research characteristics	Research problem
Artificial potential field method	It has good robustness, simple and intuitive, and good real-time performance	There is the problem of unreachable target, which is easy to fall into local optimal and local minimum	(Chao et al., 2014)	Potential field sampling to avoid local minima	Overcoming local optimality
			(Ya., 2012)	In combination with particle swarm optimization, the path nodes are dynamically adjusted	Optimal path
			(Saravanakumar & Asokan., 2013)	Fuzzy control combined with virtual target points to improve APF	Local path planning
Dijkstra algorithm	The algorithm is simple and suitable for most scenarios	The time complexity is not ideal and there are negative loops. Fails with negative edge weights	(Yan et al., 2014)	Variable length traceback array	Anti-conflict, Shortest path
			(Guosheng et al., 2024)	Dynamic grid weight assignment, shortest path global search	Shortest travel time
			(Yihu & Yanan., 2022)	Improved by adjacency list and binary sort tree structure	Shortest path
A* algorithm	High efficiency, enlightening and expandable	The evaluation function is not accurate and the space complexity is high	(Ning et al., 2022)	Adaptive search, global path planning	Search efficiency, anti-collision
			(Xianquan., 2021)	Euclidean distance, Bessel curve	Path real-time

Table 3. Research comparison of intelligent algorithms

Intelligent algorithm	advantage	shortcoming	reference	Research characteristics
PSO	Simple and easy to implement, Fast convergence, It is insensitive to the scaling of design variables and is derivative-free.	Easily fall into local optimality	(Xun et al., 2024)	Quantum physical thought
			(Xue et al., 2018)	Dynamic environment reprogramming
ACO	Good robustness, Low implementation cost	The convergence speed is slow, and it is easy to fall into local optimal	(Sun et al., 2004)	Secondary optimization, path smoothing processing
			(Biswas et al., 2017)	Multi-factor optimization
GA	Strong adaptability, global search ability and scalability	Premature convergence, low computational efficiency, easy to fall into local optimal	(Jingdong et al., 2022)	Full cover path
			(Nikolos et al., 2003)	Anti-collision, smooth path processing
			(Chen et al., 2023)	Anti-collision, Cost-Gain algorithm

Intelligent Path Search Algorithm

The intelligent bionics path search algorithm has gradually replaced the traditional path search algorithm as the standard method for handling path planning problems under complex dynamic environment information. This is due to the traditional path search algorithm's shortcomings, which include poor path optimisation effect and slow processing speed. Currently, particle swarm optimisation, ant colony optimisation, genetic algorithms, and other intelligent bionics path search algorithms are widely used. However, intelligent algorithms also have drawbacks, including slow convergence speeds, lengthy computation times, and a tendency to fall into local optimality.

Particle swarm optimization algorithm

Kennedy and Eberhart first suggested particle swarm optimisation (PSO), a parallel technique. It uses the information exchange among group members to help the entire group progress from disorder to order in the problem-solving area in order to arrive at the best solution, based on the observation of animal clusters' activity behaviour (Xue et al., 2018). PSO's efficiency can be increased by parallelizing it for concurrent processing. From a quantum mechanical point of view, (Sun et al., 2004) suggested a better particle swarm optimisation algorithm that combines the concepts of quantum physics and quantum behaviour. When updating particle placements, the algorithm concentrated on the global and local optimal positions of each particle. In order to minimise collisions in dynamic situations, (Biswas et al., 2017) presented a path planning approach for multi-agent systems based on the particle swarm optimisation technique. They were able to quickly compute a high-quality solution. A few flaws in the conventional particle swarm optimisation approach are its low precision and local optimum. Enhancing the particle swarm optimisation in several aspects is required to boost the algorithm's performance.

Ant colony optimization algorithm

The Italian researcher Dorigo developed the ant colony optimisation (ACO) algorithm, a meta-heuristic algorithm that draws inspiration from ant colonies' feeding habits. Positive feedback helps ACO, which is why good solutions are found quickly. When it comes to addressing issues such as the Travelling Salesman dilemma, ACO is especially effective. Many academics have examined the ant colony algorithm-based path planning problem in recent years and have made numerous improvements to the algorithm. To enhance the algorithm's speed of convergence, (Yuji et al., 2023) suggested a segmental pheromone updating approach based on entropy weight and incorporated a smoothing function into the state transition probability, taking path smoothness into account. The ant colony algorithm was enhanced to plan a faster convergence speed and a smoother, shorter course. An enhanced ant colony algorithm with many factors was presented by. (Jingdong et al., 2022) due to the shortcomings of the ant colony algorithm, which include limited global search capability, insufficient initial pheromones, inadequate optimisation ability, and other issues that make it unsuitable for path optimisation. The modified algorithm has a better path and fewer iterations by altering the initial pheromone concentration distribution and the heuristic function. Additionally, optimisation and robustness are enhanced.

Genetic algorithm

A heuristic random search method based on the ideas of biology, genetics, and evolution is called the genetic algorithm (GA) (Nikolos et al., 2003). The genetic algorithm has developed into a solution that is becoming more and more environment-adaptive through biological evolution in nature. Because genetic algorithms resemble natural evolution, they can overcome some of the challenges faced by standard search and optimisation algorithms. They can produce excellent solutions to a wide range of issues including search, optimisation, and learning. Addressing the parameter tuning problem which is essential to the Genetic Algorithm’s (G.A.) performance. Because global affinities are probabilistic, they cannot ensure the discovery of the global optimum. Certain flaws in the genetic algorithm include low computational efficiency and premature convergence. Researchers have made improvements to the genetic algorithm to enhance its path planning performance. In order to discover the shortest path and minimise the number of turns, (Chen et al., 2023) suggested improving it by utilising a number of grid selection models and priority heuristic search algorithms. Sun B et al.'s improved adaptive genetic algorithm (Bo et al., 2019) enhanced the crossover and mutation operators' self-adjusting strategies and added the concept of simulated annealing to the genetic algorithm's selection process. This enhanced the algorithm's ability to perform global searches and accelerated their convergence. To address the issue of reducing the proportion of infeasible paths when the initial population is generated randomly, (Meihua., 2023) proposed an obstacle avoidance strategy based on the Cost-Gain algorithm to improve the genetic algorithm, resulting in shorter path lengths and faster convergence speeds.

The research pairs of the above commonly used intelligent algorithms are shown in Table 3.

Other Algorithms

In recent years, with the continuous exploration and development of AGV, some new algorithms have been widely applied to the AGV path planning problem because of their excellent characteristics, and have achieved good results. These algorithms generally have strong path search ability, such as D* algorithm, pigeon colony algorithm, gray Wolf algorithm, artificial bee colony algorithm, etc.

CONCLUSION AND PROSPECT

The intelligent workshop relies heavily on the AGV path planning system. In this work, common AGV path planning algorithms are classified into two types: environment modelling

methods and path search techniques. This study discusses the current state of AGV path planning algorithms, analyses their benefits and drawbacks, and compares their real-time performance, algorithm complexity, environment adaptability, and planning path stationarity.

It has been discovered that, in the face of a complex workshop dynamic environment, the most significant aspect of AGV path planning is improving the practicability of the algorithm in 3D so that efficient obstacle avoidance and energy savings may be achieved. Traditional path planning approaches are inadequate for today's complicated shop operations, and AGV's dynamic model and environmental information are difficult to adequately explain. As a result, future development will centre on applying developing artificial intelligence algorithms to AGV path planning and increasing AGV intelligence.

At the moment, research into AGV route planning algorithms has made significant progress, but there are still some flaws in each specific planning algorithm, therefore the path planning field's focus remains on the development of innovative and efficient path planning and fusion algorithms. Consider potential enhancements to algorithmic efficiency, real-time adaptability, or interaction with upcoming technologies like the Internet of Things and artificial intelligence. During recent years, with the gradual application of some new algorithms (technologies) to path planning, this complementary algorithm fusion has also accelerated algorithm development by learning from one another, resulting in a sequence of increasingly great algorithms. For example, the dynamic window approach is merged with the A* algorithm, or the intelligent algorithm is integrated into a hybrid algorithm, and prospective path planning challenges are analysed and solutions are provided, broadening the scope of AGV applications.

Competing Interests

Authors have declared that no competing interests exist.

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